# Mastication: A fuel reduction and site preperation alternative*

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**Abstract**
During the fall of 2005, a study was conducted at Priest River Experimental Forest (PREF) in northern Idaho to investigate the economics of mastication used to treat activity and standing live fuels. In this study, a rotary head masticator was used to crush and chop activity fuels within harvest units on 37.07 acres. Production averaged 0.57 acres/hour (range 0.21-0.89 ac/hr). Costs average $530 per acre (range $335-$1395 per acre). Additionally, eleven fireline segments totaling 2326 feet were constructed through activity fuels using the same mastication machine. On average, 18 ft of fuelbreak was created through mastication (range 16-23 feet) combined with 4 ft of fireline (range 3-5 feet) with 100 percent mineral soil exposure constructed down the center of the trail. Total debris (including activity fuels) ranged from 26-61 tons per acre with production averaging 6.9 feet per minute (range 3.1-9.1 feet). This manuscript, concentrates on cost-analysis concerning mastication and it has shown that stand and site characteristics such as slope, residual tree density, and total acreage can significantly affect the time required to treat these areas. This research as it progresses will provide data on cost-benefit analyses comparing mastication, prescribed fire, and grapple piling/burning site preparation and fuel treatment alternatives.

**Keywords**: mastication, activity fuels, fuel treatments, site preparation

## 1. INTRODUCTION

Fuels (slash) created through harvest or fuel reduction treatments most often are treated to reduce fire risk and/or prepare sites for the establishment, growth, and survival of new seedlings (Eramian & Neuenschwander 1989, Graham et al. 2005, Graham et al. 1989). Treating activity fuels and preparing sites for planting can be conducted through the use of machines, prescribed fire, and/or chemicals (Graham et al. 2005). In nearly all settings, better seedling establishment and growth is achieved when site preparation is properly applied, thereby providing greater economic returns compared to settings in which sites are not prepared (Graham et al. 2005, Hawkins et al. 2006).

In the Western United States, prescribed fire has been extensively used for fuel reduction and site preparation. The use of fire can be relatively inexpensive compared to other methods, especially as the size of the treatment unit increases and fixed expenses can be distributed over more acres (Cleaves & Brodie 1990). Properly applied prescribed fire can decrease hazard fuels and remove undesirable ground-level vegetation without the need for extensive manual labor.

* *The 29th Council on Forest Engineering Conference. Coeur d'Alene, Idaho, July 30-August 2, 2006. W. Chung and H.S. Han, editors. pp. 137-146.*

Another popular alternative is slash piling where crawler tractors with rakes or grapple machines pile slash followed by burning. Both prescribed fire and piling, use fire to consume the material which is becoming increasingly difficult and expensive to utilize, especially near populated areas. Air quality from smoke and the chance of a fire escaping, as well as an increased presence of wildland urban structures are just a few of the concerns associated with fire use (Berry and Hesseln 2004, Shindler and Reed 1996). Moreover, prescribed fire and/or piling of slash may not be an option depending on residual tree species, which are not resistant to fire (grand fir (*Abies grandis*), western white pine (*Pinus monticola*), lodgepole pine (*Pinus contorta*), western redcedar (*Thuja plicata*) or other physical constraints (e.g. slope angle and residual stand structure) which may preclude piling of slash.

Mechanical mastication of fuels often is an alternative to both prescribed fire and piling. Mastication involves reducing the size of forest vegetation and downed material by grinding, shredding, chunking or chopping material. Initial studies have shown mastication can effectively crunch or masticate fuels created by harvest or be used to remove standing live or dead trees (Graham and Jain, 2005). Mastication can also be used to increase the distance between the base of tree canopies and the soil surface, as well as increase wood decomposition rates by insuring wood is in contact with the soil surface (Edmonds and Mara 1998; Forest Service 2005).

In order to realize the physical and biological benefits of site preparation and fuel reduction their costs need to be considered; however, limited cost evaluations of mastication are available. Moreover, what information is available lacks factors such as the influence of slope or amount of material either in the residual overstory or the amount of fuels. Both of these factors can have a major influence on the overall cost of mastication. Rummer et. al (2003) provide estimates (across all forest types in the United States) of $35-$300 per acre for prescribed fire and $100-$1000 per acre for mastication. The Dry Forest Mechanized Fuels Treatment Trials Project (Coulter et al. 2002) observed several machines masticating standing vegetation and woody material during fuel treatment and found average costs ranging from $400 to $850 per acre. The USDA Forest Service, Bonners Ferry Ranger District in northern Idaho recently estimated between $255-$400 per acre for a mini-excavator to grapple pile slash, $85-$140 per acre to burn piles, and $175 per acre for a hand crew to slash undesirable standing vegetation resulting in a total of $505-715 per acre (Wynsma 2006). In all these estimates and reports, there was very little information on the circumstances in which the individual factors (slope, residual tree density, and amount of slash to be treated) may affect the overall cost of mastication.

Information is needed on equipment limitations and production implications due to slope, residual stand density, and the amount of activity fuel to be masticated. The objective of this study was to begin evaluating different masticators, starting with a rotary head mastication machine. We investigated the cost of masticating activity fuels and determined how site (slope) and stand variables affected treatment costs. In addition, we evaluated the effectiveness and performance using a masticator to construct fireline.

## 2. METHODS

### 2.1 Study Site

A multidisciplinary study in western hemlock (*Tsuga heterophylla*) forests is located on the USDA Forest Service, Rocky Mountain Research Station, Priest River Experimental Forest (PREF) located in northern Idaho. The silvicultural objective of the study is to develop innovative silvicultural techniques that increase the forests resiliency to wildfire, disease, and insects. In addition a suite of various treatments are being tested which involve free selection (harvest), herringbone landscape patterns to decrease landscape fire risk, alternative fuel and site preparation treatments, natural and artificial regeneration of early- and late-seral species, and the evaluation of these treatments on decomposition. Slopes range from 25 to 50 percent, and unit size, species composition, and distribution of residual overstory varies. Moreover, various amounts of small material remain that requires slashing (e.g., lopping, falling). After harvest, the amount of activity fuels ranged from 24-54 tons per acre. Of the 24 units involved in the study, 10 units were masticated, 7 units will be grapple piled, and 7 units are to have prescribed fire. A cost analysis will be conducted on all units, however; only the mastication has been completed.

**2.2 Study Design**

Ten mastication study sites totaling 37.07 acres were established. Several of these units were further subdivided when mastication commenced to further stratify the units to capture variation in operating environments such as the number and juxtaposition of residual trees, structure composition, and amount of activity fuels; thus creating 19 study units (Table 1). The objective of the mastication was to create chunks (1 to 3 feet long) and insure the debris and needles and leaves were in contact with the soil surface. The masticator was also used to slash undesirable trees that remained standing after harvest.

**2.3 Mastication Machine**

A rotary mastication head was used during this study. The base machine was a 161 hp Caterpillar model 322B forest machine (FM) excavator/log loader weighing ≈80,000 lbs including the mastication head. Using the contractor's specifications, we estimated the ground pressure to be around 8 pounds per square inch (psi). In order to minimize soil compaction, the machine traveled across an area once while masticating up to a 70-foot wide strip. The FM has a ground clearance of 27 inches and an increased hydraulic motor capacity needed to turn 26 inch single grousered tracks (compared to triple grousers found on most excavators). The machine was modified to allow operation on steep slopes (> 45%) and includes larger oil pans, and a five point seatbelt used to firmly hold the operator in the seat to reduce fatigue. The overall width of the machine was 11.5 feet. The mastication head designed by the contractor weighed 6,200 lbs and had a 48 inch cutting surface. A hydraulic clamp, often referred to as a thumb, was integrated into the head design. With this thumb, the operator could grab and move material. An auxiliary 125 hp diesel engine mounted on the base machine powered an additional hydraulic system providing power for the mastication head. The hourly machine rate for this study was $300/hr, including the operator's wage and a dedicated shop truck.

**2.4 Data Collection**

Plots were established to quantify post harvest fuel amounts, residual trees, and soil surface conditions. Slash mastication and fire line construction occurred during the later half of September 2005. Elemental time and motion studies were conducted during machine operation. Unit starting and ending times were noted and using three stopwatches total time spent masticating standing vegetation (live), traveling (not masticating), and any delays were recorded. Mastication of fuels were acquired by subtracting recorded elements from the total unit mastication time. All delays were measured and categorized as either operational, mechanical, personal, or administrative. Unit areas were measured using a Trimble GeoExplorer XT GPS unit and Pathfinder office software. Fireline segment lengths were measured using a stringbox hipchain. A photographic fuel estimate series (Morgan and Shiplett 1989) was used to estimate tons/acre of woody debris on firelines. Total time to construct fireline segments were noted and recorded using a stopwatch.

Data were transferred to computer using the Microsoft Excel program. Linear regression was performed using statistical analysis software (SPSS) to create a predictive delay-free production cycle model. Independent variables are considered highly significant when the P-value < 0.05.

## 3. RESULTS AND DISCUSSION

### 3.1 Mastication

A total of 65.34 hours of mastication occurred during this study. Nineteen units were masticated totaling 37.07 acres. Table 1 details machine activity observed for each unit treated. The machine operator was moderately experienced. Early observations indicated that the operator frequently moved the machine short distances without treating slash but this non-productive machine movement decreased as the study progressed. Overall, downed fuels were treated 80% of the time, moving without mastication occurred 12%, while 8% of the time was divided equally between masticating standing live vegetation and delays (totals, table 1).

**Table 1.** Observed machine activity time (centi-minutes) listed from highest to least productive

| Unit | Move within unit (no mastication) | Cut standing (live) | Masticate | Delays | Total time | Acres |
|---|---|---|---|---|---|---|
| 8-D | 30.79 | 12.28 | 254.18 | 7.75 | **305** | **4.03** |
| 12-B | 5.92 | 2.08 | 63.20 | 4.80 | **76** | **0.91** |
| 8-B | 37.08 | 30.27 | 299.90 | 2.75 | **370** | **4.03** |
| 14-A | 17.68 | 2.10 | 104.22 | 0.00 | **124** | **1.39** |
| 8-C | 6.17 | 8.28 | 111.55 | 3.00 | **129** | **1.42** |
| 12-A | 22.95 | 2.55 | 100.87 | 21.63 | **148** | **1.61** |
| 8-A | 46.63 | 22.20 | 327.43 | 13.74 | **410** | **4.46** |
| 10 | 28.73 | 3.25 | 190.02 | 0.00 | **222** | **2.20** |
| 4-B | 11.72 | 1.40 | 163.83 | 3.05 | **180** | **1.70** |
| 23-B | 27.17 | 9.83 | 93.03 | 2.97 | **133** | **1.18** |
| 9-B | 61.47 | 20.27 | 248.52 | 56.75 | **387** | **3.28** |
| 23-A | 41.68 | 7.77 | 161.50 | 10.05 | **221** | **1.81** |
| 7-A | 27.97 | 0.37 | 288.16 | 1.51 | **318** | **2.60** |
| 4-A | 26.55 | 2.48 | 245.87 | 9.09 | **284** | **2.19** |
| 15 | 35.18 | 23.07 | 170.38 | 1.37 | **230** | **1.77** |
| 9-A | 12.93 | 2.15 | 127.51 | 3.41 | **146** | **1.09** |
| 14-B | 16.00 | 3.83 | 59.43 | 11.39 | **91** | **0.67** |
| 7-B | 5.95 | 0.00 | 74.05 | 0.00 | **80** | **0.49** |
| 16-A | 1.87 | 7.13 | 58.00 | 0.00 | **67** | **0.24** |
| **Totals** | **464 (12%)** | **161 (4%)** | **3142 (80%)** | **153 (4%)** | **3921 (100%)** | **37.07** |

Large fuels (> 3 inches diameter) were reduced on all units (Table 2). This large diameter material consisting of broken logs, long butts, tops and limbs were often converted to smaller chunks and wood pieces thereby increasing the amount of small (<3 inch) debris on most units (Table 2). Total fuel loadings (tons/acre) were reduced by mastication on 63% of the units as exemplified by the units in which the amount of fine fuels were decreased (negative values <3 inch ,Table 2). It is likely that these fine fuels were widely dispersed or incorporated into the soil surface since no fuels were removed from the site.

The machine treated an average 0.57 acres/hour with an average cost of $530 per acre (Table 2). Treating slash on steep slopes resulted in the highest cost per acre ($1396). Operating on such slopes required additional care by the operator to maintain machine stability slowing production. Working near standing trees appeared to slow production most likely by preventing the operator from freely swinging the boom. In addition the operator needed to ensure that standing trees were not damaged inadvertently by the head or by the base machine. As such additional time was required to treat these areas. During the coarse of the fuel treatments the operator controlled what live vegetation to cut and how the fuels were treated; often however, an onsite forest administrator directed the operator to "jackpot masticate" some fuels or otherwise direct the mastication operation. During such operations areas with large amounts of fuels were targeted while areas with small amounts received no treatment.

**Table 2.** Activity fuels treatment productivity listed from lowest to highest costs ($/acre)

| Unit | Pre-treatment tons/acre | Post-treatment Change in >3 inch material | Post-treatment Change in <3 inch material | Residual trees/acre | Slope (%) | Area (acres) | Production (ac/hr) | Costs ($/ac) |
|---|---|---|---|---|---|---|---|---|
| 8-D | 34.2 | -54% | 54% | 3 | 32 | 4.03 | 0.79 | $ 378 |
| 12-B | 37.1 | -32% | 175% | 3 | 32 | 0.91 | 0.72 | $ 418 |
| 8-B | 20.8 | -32% | 124% | 1 | 32 | 4.03 | 0.70 | $ 426 |
| 14-A | 47.2 | -23% | 150% | 1 | 35 | 1.39 | 0.67 | $ 446 |
| 8-C | 18.8 | -64% | 27% | 2 | 32 | 1.42 | 0.66 | $ 454 |
| 12-A | 39.1 | -51% | 110% | 4 | 32 | 1.61 | 0.65 | $ 460 |
| 8-A | 24.0 | -41% | 92% | 2 | 32 | 4.46 | 0.65 | $ 460 |
| 10 | 34.9 | -23% | 54% | 2 | 27 | 2.20 | 0.59 | $ 505 |
| 4-B | 27.6 | -37% | 66% | 5 | 31 | 1.70 | 0.57 | $ 529 |
| 23-B | 50.9 | -63% | (-4)% | 20 | 24 | 1.18 | 0.53 | $ 564 |
| 9-B | 57.8 | -65% | 90% | 6 | 45 | 3.28 | 0.51 | $ 590 |
| 23-A | 50.9 | -63% | (-4)% | 4 | 30 | 1.81 | 0.49 | $ 610 |
| 7-A | 33.8 | -32% | 224% | 2 | 35 | 2.60 | 0.49 | $ 612 |
| 4-A | 34.7 | -53% | (-23)% | 2 | 38 | 2.19 | 0.46 | $ 648 |
| 15 | 24.4 | -54% | 99% | 7 | 25 | 1.77 | 0.46 | $ 650 |
| 9-A | 47.1 | -47% | 136% | 18 | 45 | 1.09 | 0.45 | $ 670 |
| 14-B | 55.3 | -54% | 24% | 12 | 40 | 0.67 | 0.44 | $ 676 |
| 7-B | 43.1 | -32% | 66% | 4 | 35 | 0.49 | 0.37 | $ 816 |
| 16-A | 37.5 | -72% | (-14)% | 20 | 50 | 0.24 | 0.21 | $ 1,396 |

Regression analysis (Table 3) as expected shows the greatest influence on delay free mastication time is acres treated. Large units generally take longer to masticate than small units (Table 3). Regression further showed significance associating slopes with angles above 35% tending to impact mastication efficiency the greatest. Our observations agree as the unit with the steepest slope also had the highest treatment cost. In contrast to our field observations we did not find a significant relationship among the density of residual trees and machine production. Most likely slope angle, fuel structure, fuel juxtaposition, administrator intervention, and the interaction of all factors singly or in combination played a greater role in machine efficiency than residual tree density alone.

**Table 3.** Regression model predicting average mastication time (in centi-minutes)

| Coefficients | Range for independent variables (mean value) | n | $R^{2**}$ | P-value |
|---|---|---|---|---|
| 23.62 | | 19 | 0.87 | |
| +80.53*(Acres) | 0.24 - 4.46 acres (1.88) | | | 0.000 |
| +32.89*(Slope catagory) | 1 if 35% slope or greater (0 if not) | | | 0.084 |

** Adjusted $R^2$ (Includes a penalty for increasing the number of independent variables)

An integral part of using machinery in completing a task is that a variety of factors can prevent the machine from operating as planned. Over the 65.34 hours the machine worked, 2.55 hours (4% of the total time) were attributed to activities other than mastication (Table 4). Mechanical delays include several instances where the operator had to clear debris from the radiator and cool the hydraulics. Another significant mechanical delay occurred when a dead tree fell onto the boom cracking a hydraulic hose connection. Mechanical delays were minimal during our study due to a combination of significant mechanical preventative maintenance during the off-season and a relatively new machine. Due to the research aspect of this project, the administrator observing and directing the fuel treatments gave instructions or answered questions from the operator by 2-way radio. Because the operator idled the machine during these events, they were considered an administrative delay. Delays of this type are normally lower on non-research related projects. Various operational delays such as transitioning from roadside to the unit and planning the work method occurred throughout the project.

**Table 4.** Proportion of machine time not treating fuels (based 65.34 hours observed).

| Delay Category | Occurrence (%) | Example |
|---|---|---|
| Operational | 38 | Accessing unit, Clearing debris, Planning |
| Administrative | 22 | Receiving instructions from forester |
| Mechanical | 35 | Broken hydraulic hose, Cooling hydraulics |
| Personal | 6 | Operator rest periods |

### 3.2 Fireline Construction

Four firelines were constructed using the excavator with the rotary head. A total of 2326 feet of line was constructed divided into 11 sections based on slope, fuels, and/or terrain. Two operators built fireline with the masticator however neither operator had experience building line previously. The fuel break they created averaged 17.8-feet wide and included the removal of aerial fuels or trees and branches extending out over the fuel break. A 4-foot wide fireline cleared to mineral soil was constructed down the center of each segment. Pre-fuel break total debris estimates (including activity fuels) ranged from 26 to 61 tons per acre (Table 5). Under these conditions 7.3 feet per minute (or 440 feet/hour) of fuel break and fireline was constructed costing approximately $72 per 100 feet using a moderately experienced operator.

**Table 5**. Characteristics, production, and costs associated with fireline construction using a mastication machine in mixed conifer forests.

| Segment | Estimated tons/acre | Slope (%) | # of pieces by diameter size crossing fireline 3-6" | 6"+ | Production (ft/min) | Cost ($/100 ft) | Constraint |
|---|---|---|---|---|---|---|---|
| 4-1 | 49 | 38 | 11 | 12 | 6.0 | $ 83 | None |
| 4-2 | 42 | 25 | 14 | 13 | 7.7 | $ 65 | None |
| 4-3 | 61 | 30 | 16 | 26 | 9.4 | $ 53 | None |
| 6E-1 | 61 | 30 | 8 | 10 | 5.1 | $ 98 | None |
| 6E-2 | 49 | 15 | 13 | 19 | 9.3 | $ 54 | None |
| 6E-3 | 26 | 28 | 26 | 24 | 8.6 | $ 58 | None |
| 6W-1 | 45 | 25 | 17 | 27 | 4.5 | $ 111 | Activity fuels |
| 6W-2 | 45 | 10 | 39 | 60 | 8.7 | $ 57 | Remove large pieces |
| 6W-3 | 45 | 28 | 10 | 26 | 6.2 | $ 81 | Combination |
| 7W-1* | 43 | 45 | 46 | 37 | 9.6 | $ 52 | (See note) |
| 7W-2* | 43 | 24 | 20 | 14 | 18.3 | $ 27 | (See note) |

* Experienced operator: Simulated limited maneuvering, and required to build 3 waterbars on 1st segment

Fireline construction necessitates that the area of the line be free of burnable materials. In the instance of using a horizontal revolving head it had the tendency to throw branches, limbs or other slash out of the proposed burn area or across previously built fireline. These situations not only required additional fireline construction time, but in many circumstances it increased the amount of fine fuels adjacent to the protected side of fireline elevating the risk of these fuels igniting during the prescribed fire. As such the construction of firelines using a horizontal masticator needs to ensure that the material thrown by the machine does not land on the cleared fireline or in areas that would increase the risk of unwanted fire. For the most part this can be controlled by the direction the machine travels when building fireline.

In general fuel treatments using a masticator have different objectives and desired conditions compared to fuel breaks and firelines. As such building fire breaks through large amounts of fuel using a masticator may require additional resources. Considerable time is often required grinding and/or chopping large fuels into small pieces. Less time is required if these large fuels are moved outside the fuelbreak using the machine's "thumb". Though not used during our study, the addition of a ground's person following a safe distance behind the machine could reduce construction time by removing loose debris from the fireline.

A combination of operator experience and different work methods increased production of fuel breaks and firelines significantly (Table 5). For example, we used a highly experienced operator to build fireline on a steep slope. We further constrained the operator by limiting his ability to rotate the machine (simulating tight working conditions), and required three water diversion ditches be installed on the steep slope. Even with these challenges the operator was able to build a fuel break and subsequent fireline for as low as $27 per 100 feet (Table 5).

Masticators appear to be an option for building firelines through large accumulations of downed material. Moreover, our data suggest that the lines can be low impact even though they averaged 17.8 feet in width due to limited soil disturbance except for the fireline. Most often root systems and grasses remained after fuel break construction reducing erosion potential. Site impacts and rehabilitation costs can be low using a masticator, however production may be less compared to dozers.

### 3.3 Additional Research Needs

There are a variety of masticating machines manufactured by numerous firms. Ideally their costs and effectiveness could be disclosed to fully evaluate their potential for treating fuels and preparing sites for planting in western forests. Moreover, the operating efficiencies of different mastication heads (e.g., horizontal or rotary ) would also be useful information in conjunction with site factors, (e.g., slope, soils) and size, amount, juxtaposition, and composition of fuels (vegetation) being treated. This study used a large excavator based machine equipped with an auxiliary hydraulic system (80 gpm) for the mastication head. Most other machines which include feller-bunchers (80 gpm) and other excavators (40 gpm) use the same hydraulic system to power the tracks, swing the boom, and power the mastication head. As a result, our production may be higher than some masticators and research as such could address this unknown. Also smaller machines in general have lower operating costs that offset decreased production. Information addressing these issues is needed.

## 4. CONCLUSIONS

Fuels were treated on 37.07 acres in a moist, mixed conifer forest in northern Idaho using a large excavator based machine with a rotary head equipped with a thumb. To encourage decomposition, the fuels were chunked rather than chipped. A critical component of using masticators or for that matter any machine that rearranges or alters fuel structure is to ensure that the resulting fuel condition does not exacerbate fire risk, immobilize nutrients, insolate the soils, or retard decomposition. Fine fuels, < 3 inches in diameter are usually considered the hazard in most forests and their disposition is critical to determining fire risk. Therefore, masticators should chunk fuels keeping as many pieces as possible greater than 3 inches and placing them in contact with the soil surface, to encourage decomposition. Fine fuels will invariably be produced using masticators but those too should be dispersed as not to create concentrations. By far the operator has the greatest control of the size of material remaining after treatment. Because of human nature to make things look tidy and neat operators tend to grind material more than necessary to reduce the fire hazard and doing so they use more machine time which increases costs and can produce less than desirable soil and fuel conditions. Immediately after treatment fire risk most likely increases but by leaving a heterogeneous fuel loads, decomposition will most likely be accelerated and the hazard will subsequently decrease. A key to achieving the desired conditions is a competent operator and constant communication between the operator and an on-the-ground observer/administrator so the masticator creates the desired fuel conditions

In our study slash created by timber harvesting and unwanted standing trees were chunked at an average rate of 0.57 acres/hour. The slopes, fuel conditions, and residual tree densities in this moist forest were highly variable resulting in the fuel treatments averaging $530 an acre. More than any other factor slope angle tended to decrease production especially when the machine worked on slopes over 35%. Although not significant, as residual tree density increased costs tended to increase due to additional machine moving required and inability to freely swing the boom to prevent damaging residual trees. However, in addition to slope angle and tree density singly or in combination, fuel structure, fuel and tree juxtaposition, operator experience, and the desire to produce neat and tidy conditions also impacts production.

The costs we observed in this study on their face value appear to be relatively high; but the fuel and site preparation treatments occurred irrespective of the weather, no follow up activities (e.g., burning piles) were required, fire intolerant trees were protected, large and high value western white pine trees were protected, and sites have been prepared for both natural regeneration and planted trees. Prescribed fire and piling of slash are frequently used in these forests to treat fuels and prepare regeneration sites. However, both require multiple entries for the task to be completed. Often hand crews need to cut small or unwanted trees prior to either a grapple machine piling the fuels or burning them with prescribed fire. To save fire intolerant residual trees necessitates that fuels be pulled away from them and special ignition and/or protection (e.g., foam) may be needed prior to using fire. The use of fire brings issues such as impeding air quality, fire escaping, or causing residual tree mortality. Furthermore, if sites are not ready for planting trees when planned high value seedlings could be lost, potential forest growth could be lost, and the window of using prescribed fire because of shrub and grass vegetation development cold be lost. Within this context mastication costs may not be that prohibitive.

The large masticator we used built fire breaks incorporating a center fireline at an average rate of 7.3 feet per minute (440 feet/hour). Again these breaks were through moist forest slash created by timber harvesting including aerial fuels. In concentrations of large logs the masticator needed to remove these large materials using its thumb which improved fireline production. Even though fireline construction with a masticator is possible in these conditions it appeared to be far from optimum. We built fireline in various situations with the machine and with a moderately experienced operator it cost an average of $72 per 100 feet of fireline built. These costs can be greater than those built with crawler tractors but increased production and lower costs may be possible if an experienced operator was used. From a soil conservation view, masticator built firleine may require less rehabilitation due to limited soil disturbance and lack of windrowed soil/fuel combinations adjacent to fire lines which is a common occurrence with tractor built lines.

Fuel and site preparation treatments are fundamental to managing forests throughout the western United States. Because of their flexibility as to their timing, intensity, and machine types mechanical treatments are often preferred. This study illustrates how masticators can be used to fill this need demonstrated in the moist forests of northern Idaho.

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